CONCEPTUALISING A
VIRTUAL BUILT HEALING ENVIRONMENT

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ABSTRACT

The need for an understanding of how innovative solutions can be used during the design of new hospitals is growing and many National Health Service (NHS) infrastructures are facing new challenges. For instance, in 2001 the first NHS privately financed hospital, the Cumberland Infirmary in Carlisle faced problems that included: overcrowding due to inadequate bed space provision; overheating due to the design and use of a glass atrium, with maximum temperatures reaching over 35°C; and collapsed ceilings. Furthermore, the British Broadcasting Service (BBC) (2007) reported that NHS Trusts in England were struggling to meet current hygiene standards. This highlights the existence of design challenges in these hospitals in the creation of Built Healing Environments (BHEs) that enhance patient wellbeing, staff performance, operational efficiency and medical outcomes.

There have been considerable advances in Construction Information Technology (IT), especially in Computer Aided Design (CAD), Building Information Modelling (BIM), Parametric Modelling and Environmental Simulation, 3D Visualisation, Virtual Reality (VR) and Augmented Reality (AR). This paper aims to review the advances in CAD and BIM applications during healthcare infrastructure planning, design and construction. Their application to healthcare infrastructure problems will be reviewed in order to conceptualise a Virtual Built Healing Environment (VBHE). The VBHE would provide the opportunity for a comprehensive knowledge base of various healthcare infrastructure-related innovative design solutions and the construction IT software, hardware and equipment needed to develop such solutions, including a Healthcare Infrastructure Digital Mock-Up Facility (HIDMUF).

Keywords: Built Healing Environment (BHE); Innovative Design; Virtual Healing Environment (VHE)

THE BUILT HEALING ENVIRONMENT (BHE) AS THE PATIENT

Introduction to the Built Healing Environment (BHE)

The concept of the Built Healing Environment (BHE) has been given increased prominence over recent years and there has been an increased recognition of the relationship between patients' surroundings and their rate of recovery. There are many environmental factors that could contribute to patients' wellbeing and rate of recovery, including acoustics, aesthetics and air quality and the design of the BHE should be such that it optimises its environmental quality.

Built environments that support health and care delivery must develop patient focused environments that enhance patients health and recovery processes (NHS, 2004) if they are to meet their intended aims. Integrated design and construction approaches have been used to develop hospitals with physical environments that have a positive influence on patients' health and recovery outcomes (Tung, 1971; Cox and Cox, 2000). Douglas and Douglas (2005) examined patients' perceptions of hospital environments and assessed the influence of the built environment on patients' health and wellbeing. The findings suggest that supportive built environments with good layout and accessibility can create an overall inviting, calming and engaging healthcare environment for patients and their families, leading to improved patient recovery (Anonymous, 2005; Wendler, 1996).

Lawson and Phiri (2003) compared the outcomes of patients treated in modern hospital wards with similar patients cared for in older hospital environments. They concluded that the refurbished wards had better recovery results and shorter times for the healing process. However, it is difficult to determine how much of the improvement was associated with the physical environment and how much was associated with the subsequent improvement in healthcare service provision or the introduction of new technologies.

Healing environments very much depend upon the design and construction of healthcare facilities that contribute to the quality of care and to the recovery process whilst promoting therapeutic goals and enhancing operational efficiency. Previous research has linked quality of care, as well as patient health and wellbeing with the physical characteristics of the healthcare environment (Douglas and Douglas, 2004 and 2005). More specifically, there is clear evidence that the physical environment of hospitals can affect the healing process, for example: reducing the level of anxiety and stress (Beauchemin and Hays, 1998; Pattison and Robertson, 1996); shortening recovery periods following surgery through better view of surroundings and the environment (Ulrich, 1984); increasing social interaction through improved building layout; positioning of furniture to increase patients wellbeing (Somner and Ross, 1958; Baldwin, 1985); significantly diminishing pathological behaviours through the creation of supportive building environments; establishing links between built environments and patients recovery (Gabb, et al, 1992); and the provision of appropriate space and conditions to decrease patients recovery time and maximise the use of therapeutic environments (Ewing, 2005).

The concept of designing therapeutic environments is not new (Francis et al, 1999), however, relationships between environmental stimulus and response are complex and not fully understood (Canter and Canter, 1979). According to Gesler et al (2004 pp.117-128): the therapeutic environment of hospitals relates to their physical, social and symbolic design; and the aim should be to produce facilities that are: "clinically efficient; well integrated within the community; accessible to consumers and the public; and encourage patient and staff wellbeing". Many new facilities are now being delivered against very tight design and build deadlines, and which have a committed occupancy lifecycle of 25-30 years, without sufficient time to adequately plan.

Researchers in design and architectural disciplines have demonstrated that people are sensitive and responsive to the stimuli that they receive from the built environment (Beer and Higgins, 2000; Francis and Glanville, 2001; Hosking and Haggard, 1999). There is considerable evidence to support the claim that the design and construction of the built environment can have a significant impact on clinical outcomes (Sorian, 2006). Researchers in the United States of America and the United Kingdom have studied the various impacts of the built environment on patients' health, wellbeing and recovery from illness thus demonstrating how the design of healthcare environments can affect clinical and health outcomes (Ulrich, 2003; Pattison and Roberton, 1996; Beauchemin, 1996). Various studies (Hilton, 1985; Keep, 1980; Rubin and Owen, 1998) have demonstrated that the design of the built environment can help to reduce: anxiety; the need for palliative medications; tiredness; and disturbance.

The Impact of the Built Environment on Healing

Just as medicine has increasingly moved toward "evidence-based practices", where clinical choices are informed by research, the design of health and care buildings are also increasingly being guided by rigorous research linking the physical environment of hospitals and clinics to medical outcomes. Based on the evidence presented in the studies reviewed, it is apparent that healthcare (built and natural) environments exert a range of impacts on patients, staff and visitors. Healthcare facilities that are designed with specific reference to the needs of patients, staff and visitors have been shown to deliver positive outcomes, which are discussed below.

Clinical Outcomes for Healing Environment Occupants (Patients and Staff)

Ulrich et al (2004) identified and reviewed more than 650 rigorous scientific studies pertinent to understanding how the design of acute care hospitals affect patient outcomes. They showed that the conventional ways that hospitals are designed heightens stress, erodes safety and worsens outcomes. More positively, they asserted that the level of stress, risk and ineffectiveness is unnecessary as improved design of physical settings can be important in reducing stress, making hospitals safer, more healing and better places to work (Ulrich et al, 2004). Gross et al (1998) also reviewed literature on the impact of the physical environment in which treatment occurs, on both the treatment process and its outcomes, and proposed the merging of "user-friendly" architectural and environmental design components to create an integral healing environment. For example, a model of psycho-environmental approach to psychiatric hospital design was suggested in order to provide an important and effective tool in the pursuit of a humane and efficient containment and reduction of severe psychopathology. Douglas and Douglas (2004) also studied the attitudes and perceptions of patients to the built environment of hospital facilities and concluded that they prefer a hospital that is welcoming and a homely space for themselves, as well as their visitors.

Reduced Noise Improves Patient and Staff Outcomes

Research has shown that hospitals and many clinics are noisy environments (Aaron et al, 1996) with levels far exceeding World Health Organisation (WHO) guidelines. There are many potential sources of noise in hospitals and clinics, such as overhead paging, pneumatic tubes, trolleys, medical equipment, staff voices and roommates (Blomkvist et al, 2005). A second reason why healthcare buildings are too noisy is that many surfaces (ceilings, floors) are hard and sound-reflecting, enabling noises to echo, linger and travel over large areas and into patient rooms (Ulrich, 2003). Many studies have demonstrated that noise can worsen patient outcomes, for example, causing sleep loss, elevated physiological stress, increased blood pressure (Blomkvist et al, 2005) and higher frequency of rehospitalisation (Hagerman et al, 2005). Excessive noise can also reduce the quality of the working environment. Doctors, nurses and other healthcare workers may be subjected to increased levels of stress and annoyance, increased perceived work demands and reduced speech intelligibility, which all lead to a reduction in the quality of care being provided (Blomkvist et al, 2005).

Research indicates that the key to achieving a quiet healthcare building is found mainly in appropriate design of the physical environment, not in modifying organisational culture or staff behaviour (Ulrich, 2003). Ulrich et al (2004) identified important design measures for the reduction or elimination of noise through: the provision of single-bed rooms; the installation of high-performance sound-absorbing ceiling tiles or panels that sharply cut noise propagation; and replacing overhead paging with quite systems.

Improved Patient Safety

Ulrich et al (2004) suggested that patient and staff safety can be improved by reducing risk from airborne and contact-spread infections. Literature sources note that hospital air quality and ventilation (type of filter, air changes per hour, direction of airflow and air pressure) play decisive roles in affecting air concentrations of pathogens such as fungal spores and in this way have substantial effects on infection rates (Lutz et al, 2003). There is a pattern across many studies suggesting that infection rates are lower when there is very good air quality. It is well-known that a major source of contact transmission of Hospital Acquired Infection (HAI) is via physical contact, such as unwashed staff hands (Bauer et al, 1990). Ulrich (2004) suggested that the installation of alcohol-based gel dispensers at bed-side, for example, next to staff movement or work paths and directly within their visual fields can increase hand-washing rates.

A clear advantage of single rooms compared to multi-bed rooms relates to the reduction of airborne transmission through air quality and ventilation measures such as filtration, negative room pressure to prevent a patient with an aerial-spread infection from infecting others or creating positive pressure to protect an immuno-compromised individual from airborne pathogens in nearby spaces (Aygun et al, 2002; Williams et al, 2003). Multi-bed rooms are more difficult than single patient rooms to decontaminate thoroughly after a patient leaves and exacerbate the problem of multiple environmental surfaces acting as pathogen reservoirs that can potentially spread infection, for example, via environment-patient or environment-staff-patient contact sequences (Ulrich et al, 2004).

Staff Fatigue and Time for Patient Care and Observation

Poor design of floor layout can erode patient safety by increasing staff fatigue and stress, forcing nurses to spend much of their time engaged in wasteful 'hunting and gathering' activities such as fetching supplies and greatly reducing the amount of time staff have for monitoring patients and delivering direct care (Institute of Medicine, 2004). Hendrich et al (2004) showed that floor layouts with decentralised nurse charting/observation stations sharply reduce staff walking and markedly increase patient care time, especially when supplies are also decentralised and close in proximity to patient rooms. In terms of age of buildings, Macmillan (2003) compared patients in old and upgraded facilities and reported: significant reductions in aggression (for example, verbal abuse and physical violence); and less time in intensive supervisory care by psychiatric patients in the new units.

A Room with a View

Findings from many studies support the conclusions that higher levels of daylight exposure in patient rooms are effective in reducing depression and pain. Different investigators have reported that patients hospitalised for severe depression have considerably shorter stays if they are cared for in comparatively sunnier rooms in contrast to shaded or dim rooms (Benedetti et al, 2001; Campbell, 1999; Beauchemin and Hays, 1996). A study of surgical patients also established that those assigned rooms with higher daylight exposure reported suffering less pain and actually took 20 percent fewer higher dosage pain medication (Walch et al, 2005).

There has been considerable research into healthcare settings which demonstrate that visual exposure to nature can quickly and effectively lower physiological stress (for example, reduction of blood pressure) and improve emotional wellbeing. For example, surgery patients with window views of nature compared to a brick building wall required fewer potent pain doses following surgery (Ulrich, 1984). Simulations of nature (nature art, virtual reality) can effectively distract patients and thereby reduce pain and discomfort in persons undergoing procedures such as bronchoscopy, chemotherapy or burn dressing changes (Diette et al, 2003). There is also evidence that contact with nature and gardens in the healthcare workplace reduces employee stress, increases job satisfaction and may reduce attrition. Cortvriend (2005) identified the factors influencing recruitment of hospital staff to include location, car parking and transport links, family-friendly ward/patient areas and reported that open nursing stations result in staff spending more contact time with patients and are able to observe patients more easily.

Single-Bed Rooms Work Best

Based on an extremely large and varied body of research, it is clear that single rooms have several major advantages over multi-bed rooms or open bays (Ulrich et al, 2004). As noted earlier, these benefits include lower risk for hospital acquired infection and far less noise. Other documented advantages are much better patient privacy and confidentiality, better communication between staff and patients and superior accommodation for families (Ulrich et al, 2004). Single rooms also reduce patient transfers between rooms, thereby reducing costs and medical errors (Hendrich et al, 2004). Multi-bed rooms have been shown to generate more patient transfers than single-bed rooms because of incompatibility amongst roommates (Ulrich, 2005). There is also evidence of patient care units with single rooms which do not require higher nurse staffing or increased nurse/ patient ratios compared to multi-bed units (Hendrich et al, 2004). Lawson and Phiri (2000) studied two NHS hospitals and reported that 93 percent of patients in single-bed rooms stated that they: preferred them over multi-bed rooms; had shorter hospital stays; required fewer analgesics; and were more satisfied.

Benefits of Well Designed Built Healing Environments to the Healthcare System

The financial benefits of appropriately designed environments, though implicit, are far reaching and can result in improved medical outcomes, reduced stress within the working environment, reduced occurrence of infections, reduced intake of expensive analgesics, and improved job satisfaction for employees, including fewer staff absentee rates and higher staff turnover.

The Benefits of Innovative Solutions to the Built Healing Environment

Innovative design and construction solutions can lead to economic, social and environmental benefits associated with the provision of new or improved products/services, as well as decreasing the cost of existing products/services (Slaughter, 1998; Latham, 1994). This also applies to healthcare where innovative solutions can help to create appropriate healing environments, reduce costs, improve affordability and reduce risks (Seaden, 1996; Shimizu, 1997). More innovative design and construction solutions for healthcare infrastructure are needed to satisfy increasing demands for better healthcare provision and high quality healing environments. Bossink (2003) demonstrated how innovative design and construction of hospitals could improve healthcare provision, hospital staff productivity and patient recovery. Several studies have investigated the influence of building layout, ward location, and views in order to improve the patient recovery in healthcare facilities (Vogt, 1990, Taturm, et. al., 2004; Tung, 1971; Taturm, 2005). According to Toole (2001), patient healing processes and recovery rates are not only directly improved by using advanced design solutions but also indirectly improved as a result of changing user behaviour.

There exists opportunities in achieving advanced design solutions through the application of advances in construction IT such as in the areas of Computer Aided Design (CAD) and Building Information Modelling (BIM) in order to integrate innovation into healthcare infrastructure planning, design and construction.

ADVANCES IN COMPUTER AIDED DESIGN (CAD) AND BUILDING INFORMATION MODELLING (BIM)

Current generation 3D Architectural Computer Aided Design (CAD) software applications include amongst others: ArchiCAD 11 by Graphisoft; MicroStation Version 8 by Bentley Systems; and AutoCAD Revit Architecture Suite 2008 by Autodesk that consists of both AutoCAD Architecture 2008 and Revit Architecture 2008. These will be reviewed in the next sections in order to identify advances in CAD and BIM applications during healthcare infrastructure planning, design and construction. Their application to healthcare infrastructure problems will also be reviewed in order to conceptualise a Virtual Built Healing Environment (VBHE).

ArchiCAD 11 by Graphisoft

ArchiCAD is a 3D model design software and innovation has been at the forefront of Graphisoft's concepts such as its Virtual Building™ (BIM) which has challenged existing architectural design and communication methods. The idea of CAD existing and working in isolation is fast becoming obsolete and several concepts, including Object-Based 3D Modelling, Building Simulation and Collaborative Architecture, are now considered essential to CAD's optimised performance. Innovation should be a continuous sustainable process and as such Graphisoft continues to enrich the performance of ArchiCAD. It has recently extended the value of BIM through the introduction of the complementary Virtual Construction™ suite of software. It is a unique software suite, based on BIM and provides accuracy, flexibility and integration for pre-construction estimation and scheduling. This pioneering approach enables users to reduce construction time wastage, typically by 10%, as well as achieve upwards of 3% savings on the cost of every project. ArchiCAD 11 provides its users with enhanced coordination, control and virtual building functionality, which significantly enhance design, collaboration and generation of drawings.

Application of ArchiCAD to Healthcare Infrastructure Planning, Design and Construction: The Mills-Peninsula Medical Centre

Architects from Anshen and Allen in San Francisco were responsible for the scheme's seismic safety, which relied on the use of Graphisoft's ArchiCAD software. It involved the creation and use of a 3D Building Information Model (BIM) for effective collaboration and integration of the mechanical, structural, electrical and plumbing systems. The BIM model was also used in collaboration with NavisWorks™ for preconstruction clash detection simulation tests. Furthermore, the Centre's BIM model provided the opportunity for a virtual 3D environment that facilitated collaboration between the contractors and subcontractors. This permitted the exchange of design ideas, simulations and spot interferences that assisted with the avoidance of resource wastage and construction delays. It also helped develop the Mills-Peninsula Medical Centre, a five-storey building comprising: a 410,000 square-foot acute care hospital; a 200,000 square-foot medical office building; single-occupancy patient rooms with unique In-patient family accommodation that incorporated views of the San Francisco Bay's natural panorama; integrated family zones within each room; ground-level and roof-top gardens for contemplation and distraction; and increased daylight for the interior through floor-to-ceiling windows and internal courtyards; and over 30 per cent energy efficiency.

MicroStation Version 8 by Bentley

According to Bentley Systems (2007), MicroStation Version 8 XM edition is a CAD platform that drives innovation in architecture, engineering and construction. Its users include architectural, engineering and contractor teams, as well as GIS professionals. MicroStation is important because it provides a platform for BIM, it is at the heart of Bentley's DigitalPlant strategy, 47 of the 50 United States of America State DOTs standardise on MicroStation and the world is mapped using MicroStation and DGN. It is described by Bentley (2007) as a powerful, accessible and interoperable CAD platform for the design, construction and operation of global infrastructure and this is because it: is compatible and interoperable with DGN and DWG file formats popularly used for the design, construction and maintenance of 95% of global infrastructure; and drives innovation by permitting its users to customise applications using VBA; is also a standard vertical application amongst the ENR Global 150 that includes architects, engineers, cartographers and contractors. Amongst its many features, which have at their heart the drive for innovation and integration, include the following: 2D/3D Design Productivity; 3D Modelling Capabilities; Visualisation; Animation; and Graphics Performance and Presentations.

Application of MicroStation to Healthcare Infrastructure Planning, Design and Construction: An Elderly Rest Home in Taiwan; and a Hospital Design in the Netherlands

MicroStation has been used to create an elderly rest home in Taichung, Taiwan. It was able to develop the beautiful interior of this rest home with captivating rendering of its furniture and fittings and the 3D modelling and visualisation of its spatial layout. Bentley Speedikon Architectural is a single architectural BIM application for MicroStation and has been used to develop a hospital design in the Netherlands by Escade. It is an integrated BIM application for building design and construction documentation of new and existing structures that include hospitals.

AutoCAD Revit Architecture Suite 2008 by Autodesk

Autodesk (2007) describe AutoCAD Revit Architecture 2008 as a software suite that combines the capabilities of AutoCAD 2008 software, as well as the benefits of the Revit Architecture 2008 BIM application. AutoCAD Revit Architecture 2008 offers several features that facilitate innovative building design and permit freedom of design and fulfilment of efficiency. Some of these features include the following: Building Information Modelling (BIM); Parametric Components; Revit Building Maker; Rooms; Sun Studies; Site Terrain Surfaces; Detailing; Revit Worksharing; Autodesk Design Review; Revit Structure and Revit MEP Interoperability; Design Options; Interface to Energy Analysis (gbXML); "Enhanced" Autodesk VIZ 2008 and Autodesk 3ds Max 9 Interoperability; and "Enhanced" Industry Foundation Classes (IFC).

Application of AutoCAD Revit Architecture Suite 2008 to Healthcare Infrastructure Planning, Design and Construction: The Heart Hospital

According to Rundell (2007), RTKL is a major architecture, engineering and planning firm that utilises BIM and currently applies Revit on its various large-scale projects to several clients. These include its use of Revit Architecture, as well as both Revit Structure and Revit MEP. It also uses 3D DWG files that are exported from Revit and imported into 3ds Max in order to produce visualisations and this has eliminated the process of having to produce 3D models in AutoCAD. This current strategy has provided RTKL with more time available to visualise its architectural design details that include materials, textures, lighting, furniture and fittings, structures, landscape, humans and vehicles. One of the benefits identified by RTKL staff in their use of Revit BIM with 3ds Max is its ability to produce high quality visualisations that achieve accuracy and realism in its depiction of architectural designs. One of such RTKL designs is its Heart Hospital in Plano, Texas, which is a 198,000 square-foot specialty hospital.

CONCLUSION: THE VIRTUAL BUILT HEALING ENVIRONMENT (VBHE)

The Virtual Built Healing Environment (VBHE) is an emerging concept that identifies the possibilities and advantages inherent in the application of innovation, modelling, simulation and visualisation technology towards solving healthcare infrastructure planning, design, construction and operational problems. It involves integrating the capabilities of the constituents of the virtual healthcare infrastructure to rectify the problems existent in the built healthcare infrastructure. The BHE has physical limitations in terms of its possible upgrade, adaptability and flexibility, however, the VBHE does not have such limitations and provides the opportunity for seamless evolution, visualisation and documentation of innovative planning, design, construction and operational solutions to healthcare infrastructure problems. The VBHE would need to comprise a comprehensive knowledge base of healthcare infrastructure construction IT tools, software, hardware and/or equipment, detailing their advances and applicability to tackling planning, design, construction and operational problems being faced by the Built Healing Environment (BHE). These construction IT tools, software, hardware and/or equipment will consist of modelling, simulation, visualisation and virtual prototyping technologies, including the Healthcare Infrastructure Digital Mock Up Facility (HIDMUF). Current research at Purdue University's Centre for Healthcare Engineering in the United States of America have focused on developing an immersive virtual reality mock-up for the design review of hospital patient rooms. The VBHE will also comprise documentation of cases of innovative solutions that have been implemented and/or proposed to tackle healthcare infrastructure problems. The VBHE is an emerging concept that aims to integrate knowledge of the advances, capabilities, compatibilities and applicability of innovative solutions, including modelling, simulation, visualisation and virtual prototyping to healthcare infrastructure. Since innovative solutions are complex and involve many subjects, the traditional use of physical mock ups can be expensive, however, recent IT developments provide a cost effective visual alternative.

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